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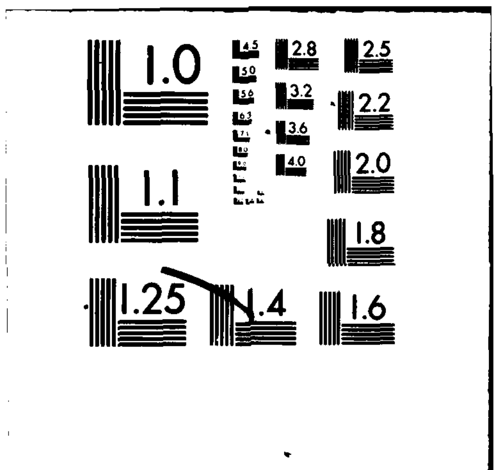

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STATISTICAL METHODS IN SOLE SOURCE CONTRACT NEGOTIATION.

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STATISTICAL METHODS IN SOLE SOURCE
CONTRACT NEGOTIATION

ABSTRACT

In this paper we describe a scenario involv~~ing~~es ill-defined elements of conflict and cooperation: the acquisition of military systems by the Department of Defense (DoD) from large corporations. ~~We will discuss how~~ current practices lead to situations in which DoD must deal with a sole source and thus forego savings which might be realized from competition between contractors. In order to deal with this situation, the Armed Services Procurement Regulations (ASPR) prescribes procedures which must be employed in the analysis and negotiation of sole source price proposals. These time-consuming procedures generate enormous proposal backlogs for government price analysts who, because of time pressures, may not be able to do a sufficiently thorough and accurate analysis upon which to base their negotiation position. This analysis paralysis also causes payment delays which, in turn, force contractors to borrow working capital and suffer capital costs. It is clearly in the best interests of all parties to expedite the processing of these proposals. This has been acomplished by developing statistical sampling and estimation techniques which, unlike some classical procedures, are not vulnerable to exploitation through the use of clever padding strategies.

This paper was written for a general undergraduate readership and presumes no formal statistical training. While some rigor and completeness was thus sacrificed, the full story would be quite easily understood by students whose curriculum included a 2 semester course in probability and statistics.

Note: This paper will appear in the first issue of the new journal, "Undergraduate Mathematics and its Applications."

1. Background

We will consider a small piece of a very large pie and how the application of statistics has saved time and money. The pie is the multi-billion dollar process of acquiring and maintaining hardware for U. S. military forces. Part of this acquisition process relies on free enterprise and competition between rival defense contracts to insure that the price is right by awarding the job to the low bidder. Nevertheless, billions are spent each year without the element of competition. This sole source scenario is the piece we shall examine.

A few examples will demonstrate why it's sometimes necessary, even desirable, for the buyer to negotiate with a single supplier.

(a) Change orders: After a prime contract is awarded and production begins, design changes are often necessitated by a change in performance requirements requested by the government or by unforseen technical problems which inevitably seem to crop up. Each design change requires a modification to the prime contract called a change order. The two parties must negotiate a price for each change - i.e. no competition.

(b) Provisioned items (spare parts, special test equipment, operation and repair manuals, etc.) The cost of these items is generally not an element of prime contract competition. Just how many spare parts will be needed is a function of product quality as well as reliability/maintainability policies. Uncertainities which exist at the time the prime contract is awarded will be greatly reduced as production proceeds, thus providing a better basis for accurate cost

analysis when the time comes to negotiate prices for these items. Since the prime contractor has already performed costly engineering, tooling and manufacturing functions to produce the total system, he would certainly win any competition for the production of spare parts. Thus, the cost of such items must be negotiated from a sole source without the benefit of competition.

(c) Major modification or repair of a system subsequent to production: Again, because of his prior investment and experience, the producer of the system has such an advantage over competitors that there is no effective competition.

In each of these examples, the sole source prepares a proposal for every requested change, provisioned item, or modification. Armed Services Procurement Regulations (ASPR) require analysis and negotiation of each proposal by some cognizant agency, usually a group of government employees assigned to perform such functions at the contractor's facility. The volume of work thus generated and the amount of money involved staggers the imagination. This volume of work coupled with insufficient numbers of government analysts and negotiators leads to large backlogs of unprocessed proposals. At one particular aircraft plant visited, there were some 625 unprocessed proposals totaling nearly half a billion dollars. At a shipyard the figures were 2,500 at .2 billion. To perform a really thorough analysis and patient negotiation would have taken the small on-site staff several months of round-the-clock work. And, during this time, the contractor would be submitting proposals for other jobs so the backlog would still exist. Because of this analysis paralysis, the

contractor has to borrow working capital to cover funds tied up in the backlog since work schedules proceed even though prices have not been finalized. Hurried analysis and negotiation can result in costly overpayment since quickness generally works against thoroughness and accuracy. Without going into further detail to support the postulate, we shall simply assume that it is in the best interest of both parties to expedite the processing of the proposals in accordance with ASPR provisions. If government cost analysts could somehow look into a crystal ball and foretell what the total negotiated price would be if each proposal were carefully analyzed and negotiated, and if such a practice were legal, the conflicting goals could be reconciled. Statistical inference can be thought of as a middle ground between business as usual and crystal ballery: By selecting a sample of proposals from the backlog, carefully analyzing the accuracy of proposed costs and negotiating a price for each sampled proposal, the resulting data can be extrapolated to estimate what the results would have been had every proposal received the same treatment.

2. Statistics Tutorial

In the section we discuss some basic ideas in probability and statistics.

(a) Fair games: A well-balanced coin is to be tossed. You pay me $20 if the outcome is heads. Otherwise, I pay you $5. So far, no one (including you) has ever agreed to play since the payoffs are unbalanced in my favor. But, I can overcome this objection with a game in which a single die is cast. I pay you $20 if the outcome is a "four." Otherwise you pay me $20. While the payoffs are equal

this time, the odds of winning favor me by 5-to-1. For a game to be fair, the payoffs should be consistent with the odds on winning. In general, if payoff c_i occurs with probability p_i for i=1,2,...,n, we define the "expected payoff" by

$$E = \sum_{i=1}^{m} c_i p_i \ .$$

For the two games proposed, from my point of view,

$$E_1 = (20)\frac{1}{2} + (-5)\frac{1}{2} = 7\frac{1}{2} \ .$$

$$E_2 = (20)\frac{5}{6} + (-20)\frac{1}{6} = 13\frac{1}{3} \ .$$

(A negative c means I pay you). A "fair game" is defined as one in which E = 0. The value of E has the interpretation that in a long sequence of plays of a game, the average winnings per play converges to E (Law of Large Numbers). A nonzero value of E means the game has a systematic bias in favor of one player.

(b) Sampling and Estimation in Finite Populations:
[References to our specific application appear in brackets.]

Associated with each unit [proposal] in a well defined collection of units called the "population" [backlog of proposals] is a set of quantitative and qualitative characteristics some of which are known [e.g. proposed price, work definition, etc.] and some unknown [what the negotiated price will be]. Upon learning the values of the unknown characteristics of units contained in a sample selected from the population, an inference is made about the value of the characteristics of the unsampled portion of the population. How should the sample be selected and how should the sample information

be used to estimate the population values? These questions are addressed in general statistics courses on design of experiments and estimation. Our limited discussion will focus on a few basic ideas. The interested reader could refer to [1] or [2] for further details.

There are $\binom{N}{n}$ distinct samples of size n which can be formed from a population of N distinct units. By defining a sampling procedure, one specifies, in effect, a probability distribution over these $\binom{N}{n}$ possible samples. For example, if one selects a sample in such a way that every unit has an equal chance at being included in the sample, a simple application of the probability calculus shows that each possible sample occurs with probability $\binom{N}{n}^{-1}$. Such a procedure is called "simple random sampling" (SRS). When auxiliary information is known [e.g. proposed price] it is often exploited in sample selection. For example, if we denote the proposed prices, ordered by decreasing size, by $x_1 \geq x_2 \geq \ldots \geq x_N$ we could select a 10% sample by selecting one proposal at random from among the first 10 and every tenth proposal from that point on. This scheme, called "systematic sampling", avoids the possibility of getting a sample with all large proposals or all small proposals. It induces a probability distribution over the $\binom{N}{n}$ samples which places zero weight on all but 10 possibilities, those 10 being equally likely. Other approaches specify conditions on the $\binom{N}{n}$ probabilities and a sampling procedure must be constructed to satisfy the given conditions. For example, "probability-proportional-to-size sampling" (PPS) specifies that the $\binom{N}{n}$ probabilities must be chosen so that the probability that proposal i is included in the sample

will be proportional to x_i. Can you think of a way to select the sample in order to satisfy the PPS criterion and prove that it works? Exercise your intuition but take care: There are some sets of x values which do not admit PPS schemes (try a sample of size 2 from a population of size 3 in which $x_1 > x_2 + x_3$). A second type of "probability sampling", called "probability-proportional-to-aggregate-size" (PPAS), requires that the probability of obtaining the sample whose indices are $(i_1, i_2, \ldots i_n)$ be proportional to $\sum_{k=1}^{n} x_{i_k}$. A procedure which meets this requirement is as follows: Select a single proposal using PPS (i.e. select proposal j with probability $x_j / \sum_{k=1}^{N} x_k$) and select the other n-1 from the remaining N-1 using SRS. This seems so close to SRS, it's hard to believe it satisfies the PPAS criterion. Can you prove that this scheme does the job?

A simple example will illustrate the difference between the last three sampling methods. Suppose N=3 with x_1=5, x_2=4 and x_3=2. If we select a sample of size n=2, there are $\binom{3}{2}$=3 possible samples: (1,2), (1,3), and (2,3). The selection probabilities are shown in Table 1.

Table 1

Sample	SRS	PPS	PPAS
(1,2)	1/3	7/11	9/22
(1,3)	1/3	3/11	7/22
(2,3)	1/3	1/11	6/22

Thus, to select a PPS sample, one could place 7 blue chips, 3 red chips, and 1 white chip in a hat. Mixing the chips and selecting one at random with the understanding that a blue chip means the

sample will be (1,2), red means (1,3), and white means (2,3). This will result in a sample which satisfies the PPS criterion. The SRS and PPAS probabilities obviously meet their respective definitions. Can you show the PPS sampling probabilities meet the requirement?

Once a sample is obtained and the values of unknown characteristics become known for those units in the sample [e.g. negotiated prices], this information is extrapolated to make an inference about the unsampled portion of the population through the use of some estimation rule. Some common procedures, phrased in terms of proposed and negotiated prices, will now be discussed. Let y_i denote the price which would result from careful analysis and negotiation of the i^{th} proposal and let $\hat{y}_i$ denote an estimate of y_i based on sample information. Let s denote the collection of sampled proposals and $\bar{s}$ the unsampled portion of the backlog. It seems reasonable that $\hat{y}_i$ ought to have the following form:

$$\hat{y}_i = \begin{cases} y_i & \text{if } i \in s \\ F(x_i) & \text{if } i \in \bar{s} \end{cases}$$

where F is a function depending on sample information. While many different F's have been suggested and studied in the statistical literature, we will mention 2 of the more common forms:

$$F_R(x_i) = \left(\frac{1}{n}\sum_s y_j \Big/ \frac{1}{n}\sum_s x_j\right)x_i$$

$$F_H(x_i) = \left(\frac{1}{n}\sum_s y_j/x_j\right)x_i \ .$$

These are called, respectively, the ratio estimator and the

Horwitz-Thompson estimator. The former multiplies x_i by the ratio of average negotiated price to average proposed price of the sampled proposals while the latter multiplier is an average of ratios. There are theoretical reasons for preferring F_R over F_H in the present context. We note in passing that $(x_i, y_i) = (2,1)$ makes the same contribution to F_H as does (200,100). Is this an undesirable property? The ratio estimator can be interpreted as follows: If the average negotiated price is, say, 90% of the average proposed price in the sample, then estimate the negotiated price of each unsampled proposal at 90% of its proposed price.

(c) Games and Statistics: Statistical inference is often described as a game between the statistician and "nature". We can imagine "nature" as a player who sets the values of the characteristics which are unknown to the statistician. The statistician obtains partial information about the characteristics by sampling and uses that information to make inferences about the unsampled units. Inference errors can be viewed as "losses" to the statistician, but we do not generally view "nature" as a hostile entity who benefits through the statistician's estimation misfortunes. In our problem, however, if we assume the contractor has a fairly good idea of what the negotiated outcome of each proposal should be, and if we define the "state of nature" as the collection of decrements $x_i - y_i$: $i=1,2,\ldots,N$, then the contractor, by setting the proposed prices, controls the state of nature. While we are not saying it's in the contractors best interest to try to selectively pad proposals in order to exploit a systematically vulnerable sampling and estimation procedure, it would

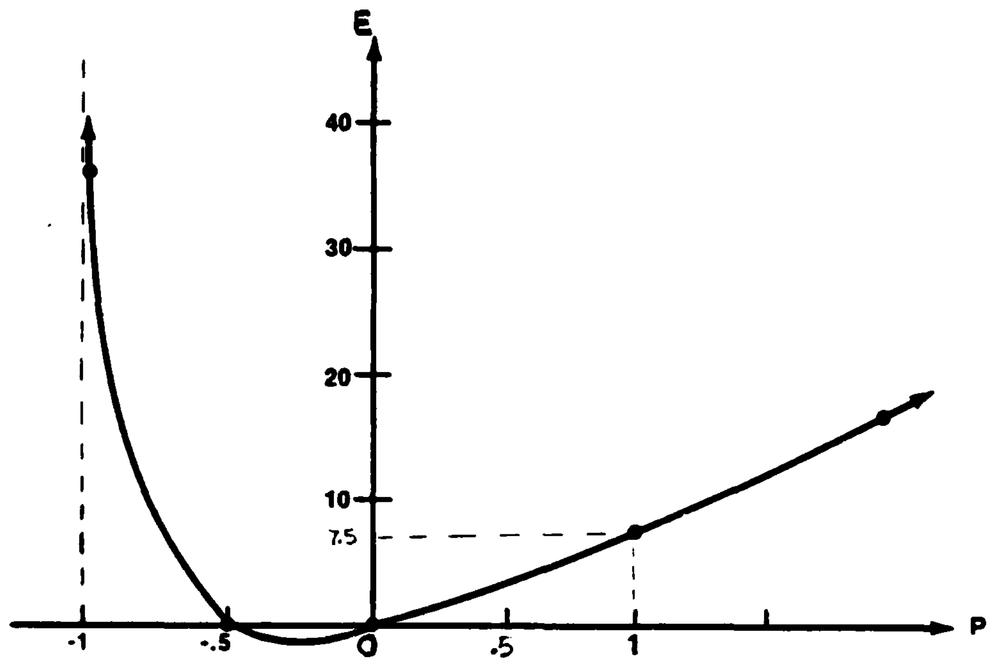
be a mistake to use such a vulnerable procedure thereby inviting gamemanship attempts.

We illustrate this potential by showing how the widely used SRS/Ratio estimation technique could be gamed. For simplicity, suppose there are only 2 proposals which ought to be negotiated at 10 and 20, respectively, but a padding factor P is added to the second proposal bringing its proposed price to (1+P)20 while the first proposal is unchanged. A sample of size 1 is selected at random. If the first proposal is sampled, no pad is found and the second proposal is not reduced leading to an overaward of 20P. If the second proposal is selected, the pad is found and the first proposal is decremented by a factor of 1/1+P resulting in an under-award of $\frac{10P}{1+P}$. Viewed as a game, the expected payoff is

$$E = (20P)\frac{1}{2} + \left(\frac{-10P}{1+P}\right)\frac{1}{2} = 10P\left(\frac{2P+1}{2P+2}\right)$$

which, as a function of P, is graphed in Figure 1.

FIGURE 1



When P = 1 we note that SRS/ratio estimation results in a situation identical to the unfavorable coin toss discussed in section 2a. If, however, a PPAS (which is the same as PPS since n = 1) sample is selected, the contractor's advantage in choosing P is nullified since

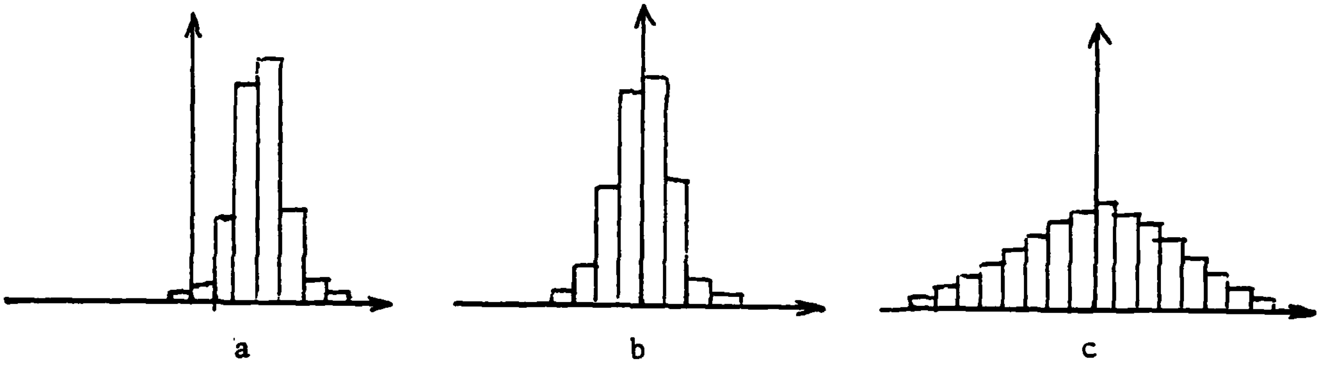
$$E = (20P)\left(\frac{10}{30+20P}\right) + \left(-\frac{10P}{1+P}\right)\left(\frac{(1+P)20}{30+20P}\right) \equiv 0.$$

Generalize the problem slightly by using pads P_1 and P_2 on proposals 1 and 2, respectively. Can you show that PPAS/ratio estimation still results in $E \equiv 0$? The quantity E is called bias when describing the systematic error of a statistical procedure and, when E = 0, we say the procedure is unbiased.

In actual sampling situations things are more complicated than in our oversimplified example. If P_i denotes the pad on the proposal whose proposed price is $x_i = (1+P_i)y_i$, the bias is a function of N, n, and the 2N numbers $\{(x_i,P_i): i = 1,2,\ldots N\}$. Nevertheless, PPAS and ratio estimation is unbiased as is shown, for example, in [2]. Although bias is an important property in our particular application, it is not the only consideration. Estimation variability, as reflected in the frequency distribution of percent overaward, must be considered. For each of the $\binom{N}{n}$ possible samples s, one could compute estimates $\hat{y}_i$ based on that sample. The total $Y. = \sum_{i=1}^{N} y_i$ would then be estimated by $\hat{Y}. = \sum_{i=1}^{N} \hat{y}_i$ and the percent overaward would be $A(s) = 100(\frac{Y.-\hat{Y}.}{Y.})$. Since the sampling plan determines the probability p(s) of obtaining sample s, we could compute (at least in principal) the $\binom{N}{n}$ pairs $\{A(s), p(s)\}$. By partitioning the range of A(s) values into suitable class intervals and summing p(s) values in each class interval, a histogram of percent overawards could be constructed as shown in Figure 2. Figure 2(a) depicts a bias in favor of the contractor while 2(b) and 2(c) are unbiased with large and small variabilities, respectively.

Unbiasedness can be guaranteed by choice of an appropriate sampling and estimation technique. Variability, while dependent on the unknown pads $\{p_i\}$, can generally be controlled by choosing a suitable sample size n.

Figure 2



3. <u>The "basket method"</u>: Our goal is to find a sampling plan and estimation technique which will be acceptable to both parties. Since they must enter into a binding legal agreement, both parties must have full information concerning the details. Error-free inference based on partial information cannot be expected but we can hope to find an unbiased procedure whose risk structure (i.e. variability) is tolerable. While PPAS/ratio estimation is unbiased, it is possible to obtain an "unrepresentative" sample in the sense that the sample contains mostly large (or mostly small) proposals. This latter objection could be removed by using systematic sampling. But systematic sampling is vulnerable to gamesmanship. The "basket method" was developed to circumvent these problems by obtaining a "balanced" sample. In an independent theoretical study [3], Royall and Herson have demonstrated the optimality of "balancing the sample" for a wide class of models.

The sample size n is determined by specifying the number of baskets to be used. The choice is based on a process called "perspective analysis" to be discussed in the next section. For now, let us assume that $(1/k)^{th}$ of the population will be sampled. Imagine k baskets numbered 1 through k into which the proposals will be placed. For the k largest proposals (those with proposed prices $x_1 \geq x_2 \geq \ldots \geq x_k$) we assign proposal i to basket i for i = 1,2,...,k. Taking the k largest unassigned proposals (x_{k+1} through x_{2k} at this time) we assign them to baskets in such a way that the largest unassigned proposal goes into the basket with the smallest total value (at this stage, this will result in x_{k+1} going into basket k, x_{k+2} going into basket k-1, ..., and x_{2k} going into basket 1). The same assignment procedure is then applied to the next k unassigned proposals (x_{2k+1}, ..., x_{3k}). That is, the largest unassigned proposal is placed in the basket with the smallest total. The procedure is continued until all proposals are assigned to baskets. In case N/k is not an integer, the last set of assignments will result in some baskets having one fewer proposals than other baskets. This initial assignment should result in nearly equal basket totals due to the sequential balancing at each stage. The goal of this basket assignment algorithm is to form k similar macro-proposals so that no matter which basket is selected, it will look like the population, only thinned a bit. Balancing on total proposed price assures that ratio estimation will be unbiased. In the computer program which does the balancing, some fine tuning is applied after the initial basket formation in order to bring the basket totals into closer agreement

(swapping proposals in the obvious way). The balancing problem can be expressed as a mixed integer programming problem, but experience has shown that our suboptimal but simple algorithm suffices quite well. By forming k (nearly) identical macro-proposals, all the standard sampling procedures (SRS, PPS, PPAS, systematic, etc.) are identical: pick one basket at random! After analyzing and negotiating each proposal in the selected basket, the decrement factor $\sum_s y / \sum_s x$ is applied to each unsampled proposal. Viewed as a population of k macro-proposals from which a sample of size one is selected, this factor is both a ratio estimator and a Horwitz-Thompson estimator. This construction has eliminated the problem of choosing between competing sampling plans and estimation strategies.

The notion of balancing can and should be extended to other relevent characteristics of the proposals besides proposed price. Proposals may differ in contractual type such as fixed price proposals, cost-plus-incentive, etc. and it may reduce variability if baskets are balanced on proposed price <u>and</u> proposed type. Level of technology (say high, medium, and low) associated with a job may prove to be related to differences in proposed and negotiated price. It is rather common for contractors to allow leeway for uncertainities associated with "fringe-of-technology" type work. Because of limited space we will not discuss balancing with respect to other characteristic except to say that, by so doing, one can substantially reduce variability. We will show an example in the next section.

4. <u>Perspective Analysis</u>: In order to give government and contractor decision makers confidence in the equity of the basket method and provide a basis for sample size determination, a simulation program was developed. The program operates on a data base composed of previously negotiated proposals which is considered representative of past experience and present conditions. Associated with each proposal are known proposed and negotiated prices along with other relevent characteristics. A random sample of size N is selected from the data base and partitioned into k baskets. One basket is selected at random and the estimation formula applied. Since negotiated prices are known, a percent overaward can be computed. This process is repeated a large number of times and a frequency distribution of percent overawards is constructed. The process is replicated for different values of k to allow the users to compare risk structures and choose a sample size (number of baskets) which best meets local conditions and requirements. Figure 3 shows one such frequency distribution used recently in deciding on a sample size for a population of about 80 million dollars.

Figure 3

Simulation Results: Relative Frequency of Percent Overaward with 4 Baskets

Class Interval Center	Cum Rel Freq	Rel Freq	Bar Chart 0.1 0.2 0.3
			I-----I-----I-----I---
-4.00	0.007	0.007	I*
-3.00	0.017	0.010	I*
-2.00	0.123	0.107	I+++++*
-1.00	0.317	0.193	I+++++++++*
0.00	0.593	0.277	I+++++++++++++*
1.00	0.780	0.187	I+++++++++*
2.00	0.920	0.140	I++++++*
3.00	0.990	0.070	I+++*
4.00	0.997	0.007	I*
5.00	1.000	0.003	I*

Table 2 contains empirical error frequencies for various class intervals of percent overaward produced by simulation. Note that there are two entries in each position. The first entry is the frequency of simulation runs where the percent overaward fell in the interval listed in the left margin for runs where only proposed price was used as the balancing criterion. The second entry, enclosed in parentheses, corresponds to runs where a tri-level characteristic was also used in balancing considerations. Note the dramatic improvement in accuracy.

Table 2

Frequencies of Percent Overaward

Percent Overaward	Number of Baskets: 2	3	4	5
0 ± 0.5%	.153 (.547)	.133 (.320)	.130 (.277)	.087 (.163)
0 ± 1.5%	.456 (.957)	.447 (.790)	.386 (.657)	.293 (.520)
0 ± 2.5%	.756 (1.000)	.683 (.957)	.586 (.904)	.447 (.790)
0 ± 3.5%	.916 -	.853 (1.000)	.773 (.984)	.633 (.926)
0 ± 4.5%	.990 -	.943 -	.870 (.998)	.773 (.994)
0 ± 5.5%	1.000 -	.987 -	.943 (1.000)	.853 (.998)
0 ± 6.5%	- -	.997 -	.979 -	.916 (1.000)

Based on inspection of these results, an agreement to use four baskets with the tri-level characteristic was reached. The sample was selected, negotiated and used to estimate the total negotiated position. Both parties to the agreement were satisfied that the results were equitable and are continuing to use sampling in this type of negotiation activity. Figure 3 is the histogram from which the 4-basket frequencies in parentheses in Table 2 were obtained.

5. <u>Conclusions</u>: The routine use of classical statistical methods in situations involving competition can be exploited when one of the parties can control the state of nature. A little common sense and some simple mathematics can be put to good use in developing useful alternative methods which are not vulnerable to gamesmanship. The level of mathematical sophistication required to understand and apply the new methods is well within the capability of undergraduate mathematics students. The new techniques are proving to be a practical way to reach an equitable and expeditious settlement in sole source negotiation situations, saving time and money for both the government and contractor.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In this paper we describe a scenario involving ill-defined elements of conflict and cooperation: the acquisition of military systems by the Department of Defense (DoD) from large corporations. We will discuss how current practices lead to situations in which DoD must deal with a sole source and thus forego savings which might be realized from competition between contractors. In order to deal with this situation, the Armed Services Procurement Regulations (ASPR) prescribes procedures which must be employed in the analysis and negotiation of sole source price

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This paper was written for a general undergraduate readership and presumes no formal statistical training. While some rigor and completeness was thus sacrificed, the full story would be quite easily understood by students whose curriculum included a 2 semester course in probability and statistics.